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A Study of Innovative Applications of Digital Technology to Promote Children's Cognitive Development in Preschool Education

Wenmin Zhou[1,*], Zhijuan Xu[1] and Fan Deng[1]
[1] School of Preschool Education, Fuzhou Preschool Education College, Fuzhou, Jiangxi, 344000, China
Corresponding authors: (e-mail: f1697541@163.com).

Abstract Currently preschool education faces the challenges of mismatch between traditional teaching mode and modern technology development, and structural contradiction between children's cognitive development needs and educational resource allocation. The wave of digitization has swept through the global education field, providing a new opportunity to solve the problem of preschool education quality improvement. In this study, the questionnaire survey method and experimental comparison method were used to analyze the effect of digital technology application on 268 preschool children. By constructing a digital technology system containing four dimensions of AR literacy, audio storytelling, doodling programming and number and shape playground, combined with three cognitive development indicators of operational IQ, linguistic IQ and total IQ, Pearson's correlation analysis and hierarchical regression analysis were used for data processing. The results showed that there was a significant positive correlation between digital technology and children's cognitive ability, and the goodness of fit of the hierarchical regression model R^2 reached 0.9673, and the significant P-value of each digital technology indicator was 0.000. Analysis of the five-year longitudinal data showed that the average student score decreased from 87.75 to 64.84 under the traditional mode of instruction, and the standard deviation increased from 6.79 to 17.48, reflecting a significant difference in the effectiveness of the instruction. The study shows that the introduction of digital technology can effectively improve the cognitive development of preschool children, providing empirical support for the construction of a modern preschool education system.

Index Terms Digital technology, preschool education, children's cognitive development, AR literacy, audio storytelling, doodle programming

I. Introduction

The rapid development of digital technology has promoted digital transformation, and the digital development of preschool education, as an important part of basic education, is of great significance [1], [2]. The relevant policies and actions of the Ministry of Education show that the state attaches great importance to the digitization of education, which points out the direction for the digital transformation of preschool education. Digital education is driving the reform and innovation of preschool education at an unprecedented speed, injecting new impetus into the development of this field, especially in the cultivation of young children's digital literacy, the enrichment of rural kindergartens' educational resources, and the change of educational methods, showing significant advantages and potentials [3]-[6]. In this context, how preschool education can respond to the opportunities brought by digital technology and realize high-quality development has become an urgent research topic.

Cognitive development is the key to the formation of children's intelligence, thinking and learning ability, which involves a wide range of perceptual sensitization, language acquisition, memory construction, thinking expansion and imagination stimulation, and is an indispensable cornerstone of children's growth and development [7], [8]. According to the insights of the famous developmental psychologist Jean Piaget, children's cognitive progress is gradually realized through their active interactions with the world around them, and this process involves the fine dynamics of assimilating new knowledge, adapting to changes in the environment, and pursuing cognitive equilibrium, and it is precisely these dynamics that drive children's cognitive abilities to move from simplicity to complexity, and from beginner's level to advanced level [9], [10]. Currently, children's cognitive development is hampered by problems such as reduced attention span and the deepening of the dilemma of corresponding screen symbol comprehension to real object comprehension [11], [12].

And some studies have shown that the use of science and technology, digital devices, digital games, digital resources and other digital means is conducive to improving children's cognitive ability, improving children's comprehension and perception, and promoting children's cognitive development [13]-[15]. Therefore, combining digital technology and carefully planning scientific and targeted educational strategies are of great practical significance for promoting children's cognitive development.

This study constructs a systematic framework of digital technology application and uses quantitative analysis to explore the mechanism of digital technology's impact on children's cognitive development. Four representative digital technology tools, namely, AR literacy, audio storytelling, graffiti programming, and number and shape playground, were selected for the study, and a complete assessment system was established by combining the three core indicators of Operational Intelligence Quotient (OIQ), Language Intelligence Quotient (LIQ), and Total Intelligence Quotient (TIQ) in the Wechsler Intelligence Scale. Basic data were collected through a large-sample questionnaire survey, and correlation and regression analyses were used to reveal the intrinsic relationship between variables, providing scientific basis and practical guidance for the digital transformation of preschool education.

II. Instructional design to promote children's cognitive development in preschool education

II. A. Exploring blended learning in a dialogic framework

In this paper, the dialogic framework is applied to the elective course “Child Cognitive Development” offered by preschool education majors.

II. A. 1) Finding the mixing point

This course is based on the training objectives of applied talents in the talent cultivation program, and the objectives of the course are to have the corresponding awareness of the construction of home and family community, to master the relevant knowledge of the family and family education, to be familiar with the basic way of constructing the home and family community, and to have the ability to communicate with parents, the ability to guide family education and the ability to organize and carry out the activities of the relevant home and family community.

The content of the course is divided into two main parts, one is about the family and family education system, and the other is about the ability that kindergarten teachers need to have in order to construct a home community, the basic ways of constructing it, and the content of interaction and communication with different types of parents. Due to the limited amount of class time, there is no way to present the content of family education in a more systematic and complete way in the classroom, so we borrowed “Family Education” offered by Prof. Li Yan of Shanghai Normal University on China MOOC as the content of online learning. Generally speaking, this course adopts the type of blended teaching [16], which is mainly face-to-face teaching and supplemented by MOOC.

II. A. 2) Sorting out the mixing process

In order to realize the objectives of the course within the limited class time, combined with the nature of the course and the advantages of online-offline blended teaching, the online learning part of the course is mainly directed to the level of children's knowledge, and thus mainly directed to what they do when they return to the face-to-face classroom.

There are three main steps in the online learning before the class: first, guiding children to watch the catechism video for learning; second, completing the corresponding self-assessment of knowledge points; and third, reading relevant learning materials.

In the face-to-face classroom, the first step is to review the online content, and then to provide additional explanations and in-depth understanding of the knowledge points. After the basic understanding of the knowledge concepts, we will start to set up the corresponding tasks or situations to guide children to apply the knowledge, and finally, we will provide more complex cases to guide children to use the knowledge to find the problem, analyze it, and put forward the countermeasures.

II. A. 3) Applications in blended learning

Parenting styles are one of the core components of the family education section, and the pre-determined curriculum objectives for this section are that children will be able to understand the four different parenting styles, analyze a case study using the parenting styles and the previous components, and initially propose strategies to solve the problem. Children need to learn the concepts of parenting styles before they can apply them in practice.

In order to achieve the objectives of the course, the concepts related to parenting styles are learned online and the offline classroom focuses on pointing to the competencies. The teaching process under the dialog box is shown in Figure 1, combining the blended teaching process of this course, assigning homework before the class, children watch the video content related to parenting behaviors in the catechism class “family education” and complete the corresponding discussion of the course questions, corresponding to the lines a and b in the dialog box of learning, the process of a is the process of teaching new knowledge, b is the feedback of children's knowledge mastery. The process a is the teaching of new knowledge, and b is the children's feedback on their knowledge, forming a teacher communication loop.

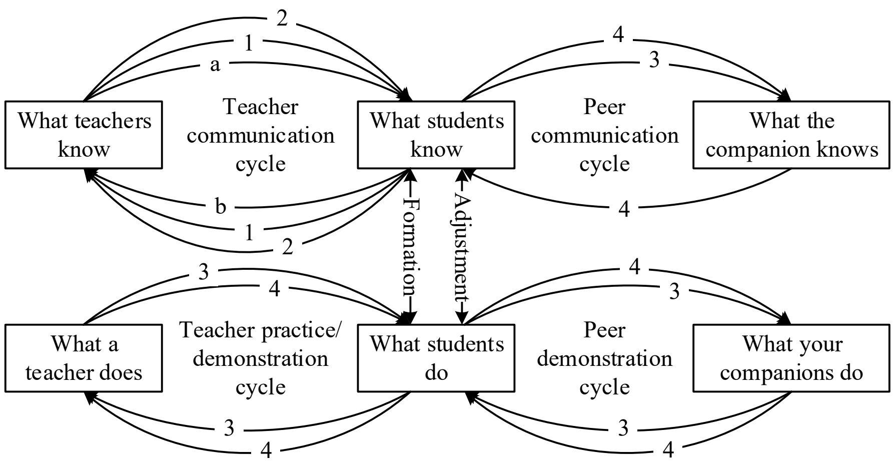

Figure 1: Analysis of the teaching process under the dialogue framework

II. B.Research design and methodology

II. B. 1) Questionnaire design

The research tools are divided into two categories: the first type is the basic personal background information of the participants, which is multiple-choice and fill-in-the-blank items; The second category is the Chinese Learning Motivation Scale and the Chinese Learning Motivation Intensity Scale. Both scales are in the form of a five-level Likert scale of "strongly agree", "agree", "uncertain", "disagree", and "strongly disagree". The selection of participants in this survey first considered the balance of the number of children among the five kindergartens. A total of 300 questionnaires were sent to parents of children, and 276 questionnaires were returned, of which 268 were valid. A total of 268 samples were statistically analysed, and the personal background information of the participants was as follows: 117 and 151 men and women, respectively, with ages ranging from 25 to 40.

II. B. 2) Scales to promote children's cognitive development in preschool education

Indicators for promoting children's cognitive development in preschool education include three components: Operational IQ, Verbal IQ and Total IQ. The level of digital technology includes 3 parts: AR literacy (to enhance children's interaction with reality), audio storytelling (to develop children's verbal logic and imagination), and doodling programming (to enlighten children's computational thinking and causal reasoning skills). Each indicator contains 3 topics, which are named with the rule that they are sorted by 123 after the short name of the main factor. For example, the three topics of the Doodle Programming (FI) indicator are: repeating the jumping instruction 3 times; the shortest path to avoid obstacles; dragging red blocks to make the car move forward, which are named FI1, FI2, and FI3 in this paper.The scales for promoting children's cognitive development in preschool education are shown in Table 1.

Table 1: The scale of the cognitive development of children in pre-school education

	Digital technical level	For short	Children's cognitive development indicators	For short
Indicators of the cognitive development of children in pre-school education	AR knowledge	AR	Operating IQ	OIQ
	Voice story	VS	Language IQ	LIQ
	Graffiti programming	GP	Full intelligence	FI

II. B. 3) Questionnaire validity and reliability

The KMO test and Bartlett's sphere test were performed on the six variables of the Children's Cognitive Structure Scale using SPSS software: the KMO value was 0.7935>0.5 and the approximate chi-square value of the Bartlett's test was 325.7419, corresponding to a probability value of P=0.000<0.001, making it suitable for factor analysis.

Then, of the principal component factors conducted, three factors were extracted using oblique rotation, which explained 35.75%, 22.64%, and 13.07% of the overall and cumulatively explained 71.46% of the total variance, which indicated that it was more appropriate to extract three factors. The loadings of each question on the factors and the naming of the factors are shown below:

Factor 1 included VS1, VS 2, VS3, GP1, GP2, and GP3 questions, reflecting the fact that audio storytelling and doodling turned out to be a source of interest from the digital technology provided, and was therefore named Source of Interest.

Factor 2 included AR1, AR2, AR3, LIQ1, LIQ2, LIQ3, and FI3 items, AR Literacy and Verbal IQ which positively evaluated and encouraged children's cognitive abilities, so it was named Cognitive Encouragement.

Factor 3 includes OIQ1, OIQ2, OIQ3, FI1 and FI2 question items, reflecting the effect of digital technology on children's operational IQ and full IQ, which is intrinsic and not affected by external factors, so it is named intrinsic ability.

III. Analysis of the effect of the application of digital technology in children's cognitive development

III. A. Analysis of Statistical Results on Teaching Effectiveness of Courses

III. A. 1) Distribution of test scores in basic preschool education courses

The sample data were obtained from the paper scores of CG kindergartens in Province G for five consecutive years of basic preschool education course exams, with each natural class or session as a sample space, and children's scores of absentees and retakes were removed to ensure the reliability of the data. Separate χ^2 goodness-of-fit tests were performed on children's grades for each academic year. Confidence level $\alpha = 0.01$ was set. Divide each tenth of a child's score into intervals. The χ^2 goodness-of-fit test showed that the original hypothesis was not accepted for school years 2020-2021 and 2021-2022, i.e., children's scores did not conform to a normal distribution in school years 2020-2021 and 2021-2022, while scores in the other school years conformed to a normal distribution.

The histogram of the frequency distribution for the 2019-2020 school year is shown in Figure 2. There were large deviations from the fitted curve of normal distribution in some score bands in school years 2020-2021 and 2021-2022, which also verified the results of the analysis of the medium χ^2 goodness-of-fit test. Although there was also a large deviation between the 60-70 score bands and the fitted curve of normal distribution in the 2023-2024 school year, it did not affect the normal distribution of the subjects. It can be seen that the χ^2 fit goodness-of-fit test is used to verify whether the data samples conform to normal distribution with high accuracy. Of course, the transcripts that do not meet the normal distribution simply use the four indicators of normal distribution to evaluate the teaching effect, and its bias is obvious.

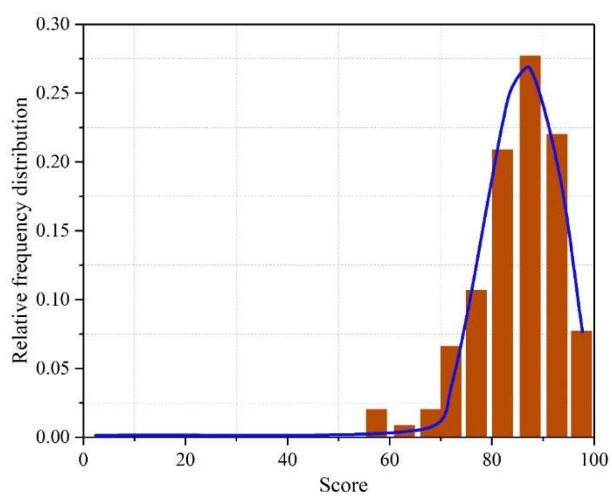

Figure 2: 2019-2020 frequency distribution histogram

The histogram of the frequency distribution for the 2019-2020 school year shows that the normal fit is the best, intuitively reflecting that children's overall learning outcomes are benign. The following two school years did not fit the normal distribution and showed the typical “positive shift” where the peak of the normal fit curve was to the left of the peak of the frequency histogram, as shown in Figure 3 of the frequency distribution histogram for the 2020-2021 school year. The results show that there is a small convex peak in the 55-60 score band. In addition, the occurrence of a small convex peak in the 65-75 score band in the 2021-2022 school year makes the fitted curve shift to the left as a whole. Whereas, although small peaks in frequency occurred between 20-30 scores in school years 2022-2023 and 2023-2024, the lone small peaks were episodic.The histogram of the frequency distribution for school year 2023-2024 is shown in Figure 4. In addition, the fitted curve of the normal distribution for the school year was flattened, indicating a decrease in the average peak. The slightly positive skewed distribution also indicates that the frequency of the distribution in the higher score bands is slightly greater than the frequency in the lower score bands, which is still an acceptable normal distribution within the confidence level of the χ^2 goodness-of-fit test. It is worth noting that comparing the academic years 2022-2023 and 2023-2024, we can see that the highest peak of the frequency is significantly higher than the peak of the fitted curve (mean), especially the difference between the two in the academic year 2023-2024 is even larger, which belongs to the typical “positive skewness”, that is, the concentration of the scores in a certain score band, making the differentiation of the test scores decrease. This is a typical case of “positive skewness”, i.e., a concentration of scores in a certain score band, resulting in a decrease in the differentiation of test scores and a significant reduction in teaching effectiveness. In five consecutive school years, the test questions come from the same test bank, and the difficulty index is comparable. Although the test scores of children in the 2023-2024 school year are in line with the normal distribution, the average scores have dropped significantly compared with those of previous years, and there is the phenomenon of “double hump” in which the scores are disconnected, i.e., there is a small hump at about 35 points and a big hump at about 70 points, which indicates that the actual teaching effect is poorer. This indicates that the actual teaching effect is poor.

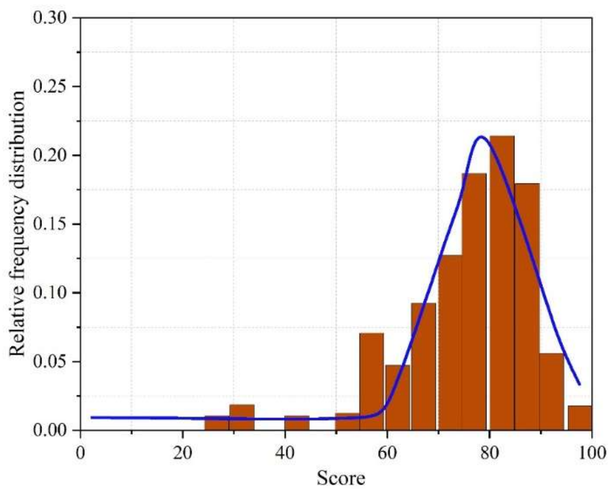

Figure 3: 2020-2021 frequency distribution histogram

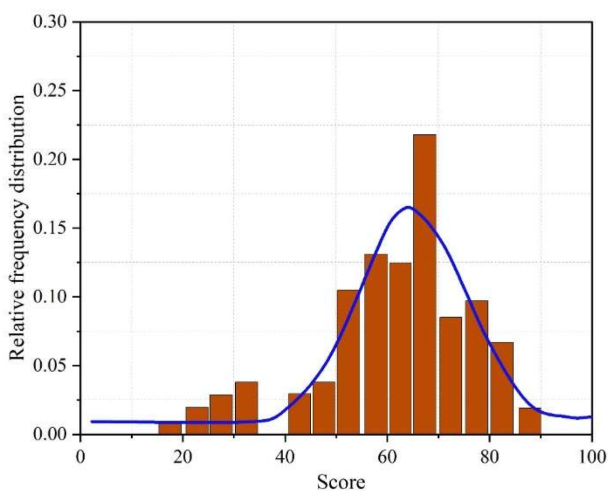

Figure 4: 2023-2024 frequency distribution histogram

III. A. 2) Results of examination results in basic preschool education courses

The results of changes in the mean scores of children's preschool grades and their standard deviations for each school year are shown in Table 2. The average scores show a clear downward trend, with 110 students taking the exam in 2023-2024, failing as many as 46 students, with an average score of 76.49, well above the passing line (60 points). By comparing the standard deviation, the standard mean of the standard deviation in the general evaluation of teaching effectiveness is about 13.86, and the upper and lower limits are 17.48 and 6.79 points, respectively, and the large standard deviation of the grades indicates that the students are more polarized and that the teaching effectiveness is not good. It can be seen that both larger positive shifts and positive skewness cause an increase in the value of the standard deviation. The factors contributing to the poor teaching effect in a certain school year are multiple, including the social atmosphere, personal ideals and pursuits, and the management situation of the school, and it cannot be ruled out that the overall learning literacy of a certain class of students is poor. With the large number of domestically produced smart electronic devices, represented by cell phones, on the market after 2020, certain students are addicted to cell phone games; This, coupled with the fact that students' cognitive development courses are scheduled for parental supervision and are recorded and uploaded on electronic devices, has led to a significant increase in the chances of students using electronic devices “in the open”, resulting in some parents neglecting their students at the preschool level, and resulting in uneven performance. In addition, the kindergarten basic curriculum is taught in large classes, with less interaction between teachers and students, and fewer classroom hours. Classroom teaching time is tight, making it difficult for teachers to keep abreast of students' learning status. Therefore, in order to keep up with the fast-developing information age, the content and teaching methods of the curriculum should also be changed.

Table 2: The average number and the deviation of the standard deviation

Year	Average performance	Standard deviation
2019-2020	87.75452	6.78733
2020-2021	76.61199	14.42308
2021-2022	79.66629	16.60068
2022-2023	73.55769	13.99887
2023-2024	64.84729	17.47738

III. B. The Impact of Digital Technology and Cognitive Skills on Preschoolers

In this study, with reference to the screening and comparison of published methodological reviews on the measurement of cognitive development in preschool children with reference to the application of digital technology in preschool education, the most commonly used and reasonable parameters were selected as innovative applications for preschool education to promote children's cognitive development. Considering the frequency of cell phones and other electronic devices in preschool children's daily life and the mobilization of children's motivation to learn and thinking ability, this paper adds Number and Shape Paradise (CP) to the digital technologies below to help children build number sense and geometric cognition in the game.

Indicators of children's cognitive development in preschool education include “Operational IQ, Verbal IQ, and Total IQ”. The level of digital technology includes 4 parts: AR literacy, audio storytelling, doodling and programming, and number playground.

III. B. 1) Pearson's correlation analysis

Correlation analysis refers to a class of methods used to describe the analysis of two or more elements of a variable that have a correlation to measure the statistical inference of the closeness of the correlation between the variables. Correlation coefficients between two or more numerical variables include Pearson's correlation coefficient, Kendall's and Spearman's correlation coefficients, whose values have no unit and have a magnitude between (-1, 1), with the magnitude of the absolute value indicating the closeness of the correlation, with 0 indicating that there is no linear correlation between the variables, and with the plus and minus signs indicating the direction of the correlation, which will be used in this study. The bivariate correlation between digital technology and cognitive ability will be conducted using Pearson analysis.

The Pearson correlation analysis of digital technology and cognitive ability of preschool children is shown in Table 3, Note: ***, **, * represent the significance level of 1%, 5% and 10% respectively. From the Pearson correlation analysis coefficient table, it can be seen that preschool children's digital technology and cognitive ability have a certain correlation, in which there is a positive correlation between verbal IQ and operative IQ, full IQ, AR literacy, phonics storytelling, doodle programming, and counting and shaping music; there is a positive correlation between operative IQ and full IQ, AR literacy, phonics storytelling, and doodle programming and there is a negative correlation between operative IQ and counting and shaping music; there is a negative correlation between operative IQ and counting and shaping music. There was a negative correlation between Operational IQ and Full IQ, AR Literacy, Phonics Stories, Doodle Programming, and Number Shapes; a positive correlation between AR Literacy and Phonics Stories, Doodle Programming, and a negative correlation with Number Shapes; a positive correlation between Phonics Stories and Doodle Programming, and Number Shapes; and a positive correlation between

Doodle Programming and Phonics Stories.

Table 3: Digital technology and cognitive Pearson correlation analysis

	LIQ	OIQ	FI	AR	VS	GP	CP
LIQ	1	0.0000***	0.0000***	0.3637	0.7799	0.0286**	0.0995*
OIQ	0.4572	1	0.0000***	0.746	0.3669	0.7383	0.7589
FI	0.7479	0.904	1	0.4559	0.2685	0.1292	0.4474
AR	0.0796	0.0308	0.067	1	0.6114	0.7292	0.0636*
VS	0.0238	0.0846	0.1073	0.0506	1	0.0000***	0.0000***
GP	0.198	0.0342	0.1407	0.0323	0.446	1	0.0000***
CP	0.1532	-0.0327	0.0727	-0.1721	0.4039	0.7671	1

III. B. 2) Stratified regression analysis

Hierarchical regression analysis can be divided into multiple levels to analyze the degree of influence of the newly added independent variable on the dependent variable by examining the difference between the fit of the model at the previous level and the model at the next level (X variable was set as Verbal IQ, Operational IQ, AR Literacy, Phonetic Storytelling, Doodle Programming, and Numerical Shape and Music), and the Y variable was Total IQ, which, if it presented a significance ($P<0.05$), was used to explore the relationship of the influence of X on the Y influence relationship. Detailed conclusions were drawn by analyzing the data on digital technology and cognitive skills of preschoolers thereby analyzing the fit of each model.

The stratified regression analysis of digital technology and cognitive ability of preschool children is shown in Table 4, Note: ***, **, * represent 1%, 5%, and 10% level of significance, respectively. The results show that: based on the stratification model control layer, including operational IQ, verbal IQ between the significance P-value of 0.000***, the level of significance is presented, reject the original hypothesis, the model is valid, at the same time, the model's goodness of fit R^2 is 0.9568, the model is more excellent performance.

Stratum 1: The p-value of significance between including Operational Intelligence, Verbal Intelligence and AR Literacy is 0.000***, which presents significance at the level, while the model's goodness-of-fit R^2 is 0.9679, and the model performs better.

Stratum 2: The p-value of significance between including Operational IQ, Verbal IQ, AR Literacy, and Phonological Story is 0.000***, which presents significance at the level while the model's goodness-of-fit R^2 is 0.9622, which is a better model performance.

Stratum 3: The p-value of significance between including Operational Intelligence, Verbal Intelligence, AR Literacy, Phonological Storytelling, and Doodle Programming is 0.000***, which shows significance at the level of validity of the model while the model's goodness-of-fit R^2 is 0.9668, which is a relatively good performance of the model.

Stratum 4: The p-value of significance between including Operational Intelligence, Verbal Intelligence, AR Literacy, Phonics Storytelling, Doodle Programming, and Counting and Shape Music is 0.000***, which presents significance at the level of rejection of the original hypothesis, and the model is valid, while the model's goodness of fit, R^2, is 0.9673, which shows that the model performs relatively well.

It can be seen through the above analysis that with the addition of the four control variables of AR literacy, phonics story, doodle programming, and counting and shaping music, the significance P-value becomes more and more obvious in terms of the level of performance, and in terms of the degree of fit of the constructed model, the value of the goodness of fit, R^2, is much more excellent, which reflects that by increasing the time of the activities of the preschool children's phonics story, doodle programming, and counting and shaping music, it is possible to play a positive role in the preschool children's cognitive abilities positively.

In summary, the results of a multifaceted analysis of the effects of preschoolers' motor rest and relaxation behaviors on cognitive functioning showed that age and gender differences had a significant impact on the development of cognitive functioning and the improvement of digital technology in preschoolers.

Table 4: Hierarchical regression analysis of digital technology and cognitive ability

Parameter	Control layer	Layer 1	Layer 2	Layer 3	Layer 4
	Constant	34.1022	33.9304	32.7725	32.8801
OIQ	1.5853	1.5898	1.5812	1.5846	1.585
LIQ	1.7214	1.7112	1.7146	1.695	1.6934
AR	--	0.0000	0.0000	0.0000	0.0000
VS	--	--	0.0055	0.0038	0.0042

GP	--	--	--	0.0103	0.0121
CP	--	--	--	--	0.0007
R2	0.9568	0.9679	0.9622	0.9668	0.9673
Adjust R2	0.9515	0.9538	0.9484	0.9552	0.9532
F	1208.0006	799.9945	612.0031	487.9997	405.0005
P	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
ΔR2	0.9472	0.0000	0.0004	0.0000	0.0000
ΔF value	1207.9992	0.3491	2.7225	1.0323	0.0063
ΔP	0.0000***	0.7887	0.0355	0.4016	1.0000

IV. Conclusion

By systematically analyzing the effects of digital technology on children's cognitive development in preschool education, this paper found that digital technology application has significant positive effects. Stratified regression analysis shows that when four digital technology variables, namely AR literacy, audio storytelling, doodle programming and number and shape playground, are introduced, the model fit goodness of fit improves from 0.9568 in the basic control layer to 0.9673, indicating that digital technology can effectively explain the variation in children's cognitive ability. Pearson's correlation analysis confirmed a significant positive correlation between verbal IQ and each digital technology indicator, with correlation coefficients varying between 0.0238 and 0.7799. Comparing the longitudinal data of the traditional teaching mode, it is found that the teaching effect in the 2019-2020 school year is the best, with an average score of 87.75, while the average score in the 2023-2024 school year drops to 64.84, a decrease of more than 22 points, while the proportion of failing students is as high as 41.8%, which fully explains the serious challenges faced by the traditional teaching mode. The scientific application of digital technology not only enhances children's cognitive ability, but also improves the stability and consistency of the teaching effect, which provides a feasible path for the quality improvement of preschool education.

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